IOP Conference Series: Earth and Environmental Science

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To cite this article: Shuping Gao *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **233** 042039

IOP Conf. Series: Earth and Environmental Science 233 (2019) 042039 doi:10.1088/1755-1315/233/4/042039

A Novel Islanding Detection Method Using dq Harmonic Impedance Component

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Abstract. By analyzing the harmonic impedance of the inverter, it is found that the characteristic frequency impedance signal is different when it is connected to grid or when it is disconnected to grid. According to this difference, a new detecting islanding method is proposed, which is implemented by using the difference of dq harmonic impedance component at the PCC point when it is connected to grid or when it is disconnected to grid. Simulation results show that islanding state can be detected quickly and effectively with this method. And compared with the traditional passive detection method, the method proposed can achieve non-blind detection and has no influence on power quality.

1. Introduction

With the shortage of energy resources and environmental pollution, the generation technology of renewable clean energy has becoming the focus of global research. Solar photovoltaic power generation has becoming one of the most promising distributed power sources because of its flexibility, cleanness and universality. Through the photovoltaic grid connected power generation system, the solar energy is converted into electricity, and the power is transmitted to the power grid, which is the main form of solar energy utilization.The islanding effect is a phenomenon that the distributed generation system is still connected to the grid and operates in an independent state to supply the local load when improper operation, electrical faults or natural factors cause the abnormal power grid[1], as shown in Figure. 1.

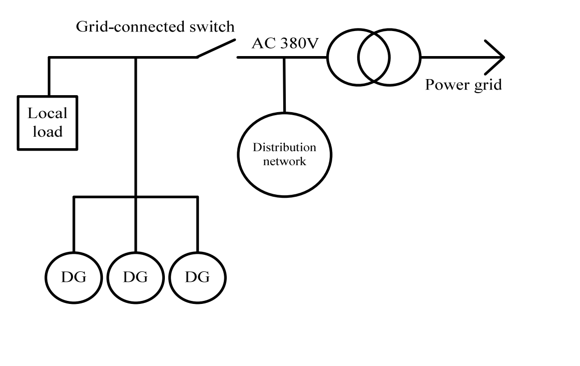


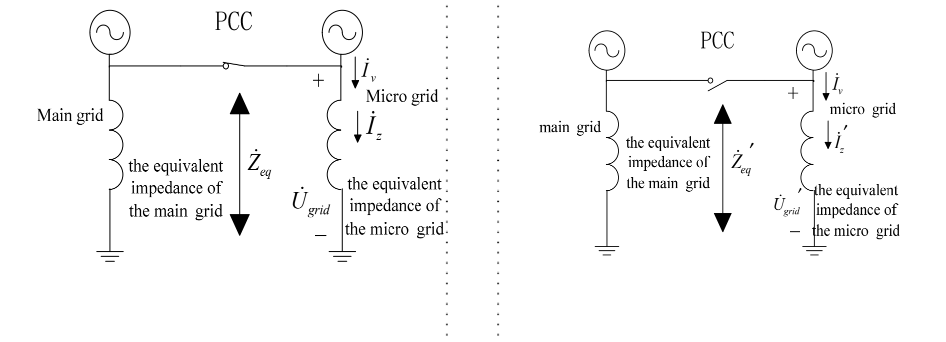
Figure. 1 Islanding of distributed generation system

As can be seen from Figure.1, the distributed generation system connects the distributed power to the local load through the grid connected switch. When the power grid is running normally, the power output of the grid connected power generation device does not match with the load demand power. And even the mismatch degree of power between them is greater. At this point, if the grid is disconnected, the mismatch between power levels necessarily results in changes of voltage or frequency in power system, so islanding detection can be implemented by detecting these changes before and after islanding. However, when the power is matched, the output power of the distribution power is equal to the power of the load demand. Islanding occurs when the branch power supply side and grid side power deficiency is the same approximately, so change of voltage and frequency at the Point of Common Coupling (PCC) is very small. In this case, it is difficult to detect islanding by detecting the change of voltage and frequency with passive detection method, grid connected power generation equipment will continue to supply power to the load. At this situation, an island system consisting of distributed generation system and load is formed. Island effect not only affects the safe operation of large power grid, but also may cause personal injury to electric power personnel. Therefore, islanding detection is one of the key technologies of grid connected fault detection, and it has important significance. The existing islanding detection methods mainly include communication based islanding detection method and local islanding detection method[2]. Islanding detection method based on communication uses communication method to transfer switch state information to carry out the islanding detection.The method is efficient, but the cost is too high and it is not practical[3]. The local islanding detection method detects the island effect by monitoring the terminal voltage and current signal of the grid connected generator. It can be divided into passive and active method, in which the passive method can determine the occurrence of the island by monitoring the operation parameters of the system[4-6]. And the active method is to inject a certain disturbance to the system constantly to implement islanding detection. When a parameter exceeds the allowable range, the islanding is determined[7-10]. Passive and active methods have advantages and disadvantages. In general, passive methods have relatively large non detectable regions(NDZ)[11]. Although active methods reduce the detection area effectively, it will affect the power quality more or less[12].

On the basis of passive islanding detection method, a method to detect islanding using dq harmonic impedance component is proposed in this paper. This method can be realized only using the specific frequency signal (250Hz) data, and the hardware is easy to implement. The islanding effect can be detected quickly and effectively without affecting the power quality of the power system, and the transient response of the system can not be disturbed. The island effect can be detected quickly and effectively in the most severe case of the island, and the time requirement for islanding detection in IEEE Std. 1547 is satisfied.

2. The principle of islanding detection based on DQ harmonic impedance component

The method of detecting islanding fault by using dq harmonic impedance component is based on monitoring the harmonic impedance at the Point of Common Coupling (PCC). Dq harmonic impedance component at the PCC point is relatively small in normal grid operation, and it is larger in islanding operation. According to this difference of dq harmonic impedance component at the PPC point, islanding state can be carried out. The equivalent impedance diagram of the grid connected state and the isolated island state is shown in Figure. 2.



（a）Grid connected state （b）Island state

Figure. 2 Schematic diagram of equivalent impedance change at PCC point

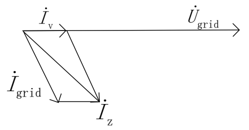


Figure. 3 The vector diagram of PV grid current

The corresponding vector diagram is shown in Figure.3.

Usually, the grid can be considered as an infinite capacity system. From Figure. 3, $\dot{U}_{grid}$ is the grid voltage, which is also the voltage at the PCC point, and maintain stability. $\dot{I}_{grid}$ is the main input current to the micro network. $\dot{I}_v$ is the inverter output current, $\dot{I}_z$ is load current. When the grid is the island operation, $\dot{I}_{grid}=\dot{0}$. The inverter side voltage can not be changed and remains $\dot{U}_{grid}$. So when the islanding occurs, due to the loss of power grid support, distributed generation system separately power supply to the local load, harmonic impedance resulted from harmonic current is far greater than the system impedance of the local load, the harmonic content will greatly enhance.

The PV inverter vector diagram using grid voltage orientation is shown in Figure. 4.

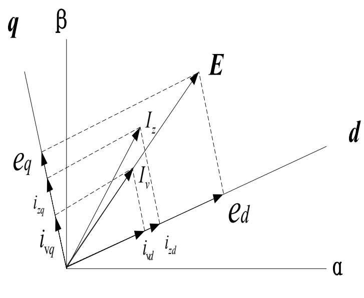


Figure. 4 Vector of photovoltaic inverter based on grid voltage orientation

From Figure. 4, in the synchronous rotating coordinate system with the voltage orientation of the network, there is

$$\begin{cases} \left|\Delta Z_{\mathrm{d}}\right| = \left|\dfrac{e_{\mathrm{d}}'}{i_{\mathrm{vd}}'} - \dfrac{e_{\mathrm{d}}}{i_{\mathrm{vd}}}\right| \\ \left|\Delta Z_{\mathrm{q}}\right| = \left|\dfrac{e_{\mathrm{q}}'}{i_{\mathrm{vq}}'} - \dfrac{e_{\mathrm{q}}}{i_{\mathrm{vq}}}\right| \end{cases} \tag{1}$$

ΔZ_{d} , ΔZ_{q} are the d axis component and the q-axis component of harmonic impedance, respectively. e_{d} , e_{d}' are the d-axis potential of the voltage harmonic in normal state and isolated island state, respectively. e_{q} , e_{q}' are the q-axis potential of the voltage harmonic in normal state and isolated island state, respectively. i_{vd} , i_{vd}' are the d axis potential of current harmonic in normal state and isolated island state, respectively. i_{vq} , i_{vq}' are the d axis potential of current harmonic in normal state and isolated island state, respectively.

Through fast fourier transform (FFT) to extract the specific subharmonic (250Hz) dq impedance components, the island can be detected quickly. Because the harmonic generation is a function of the inverter itself, it has nothing to do with the amount of power shortage and grid side. So this method can overcome the shortcomings of the detection blind area of traditional passive detection methods.

3. Isolated island identification and criterion

As can be seen from the previous section, the harmonic voltage of PCC point changes before and after islanding occurring. In view of the above phenomena, the characteristic frequency (5 subharmonic) impedance can be monitored and corresponding setting values are set up. When it is exceed the threshold, the island detection can be implemented, and the setting rules are as follows:

$$|\Delta Z_{5\mathrm{d}}| > Z_{\mathrm{set1}} = 0.2\Omega \tag{2}$$

$$|\Delta Z_{5\mathrm{q}}| > Z_{\mathrm{set2}} = 0.2\Omega \tag{3}$$

In (2) and (3), $\Delta Z_{5\mathrm{d}}$, $\Delta Z_{5\mathrm{q}}$ are 5 harmonic impedance d,q component, respectively. Z_{set1} , Z_{set2} are the setting value of 5 harmonic impedance d, q component, respectively.

4. Islanding detection logic

According to the above analysis, an anti islanding strategy operation logic diagram can be constructed using harmonic impedance d and q component to detect islanding, which is shown in Figure. 5:

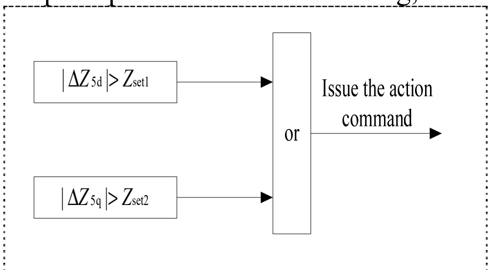


Figure. 5 Action logic diagram of anti islanding strategy

5. Simulation Analysis

A single PV grid connected generation system is established in PSCAD, the output voltage of PV array is 600 V, the output current is 1000 A, the output voltage of inverter is 270 V and the output power is 500kW.The local load adopts the RLC parallel circuit (at this time the island is in the most serious state), the quality factor is 1, R=0.4673Ω, L=0.001487 H, C=6812 uF . And the running time of power system is 1.2s, the islanding occurs at t=1s moment, the sampling frequency is 4.8kHz, and the duration time is 0.2s (0.9-1.1s). The system operating parameters are shown in Figure. 6.

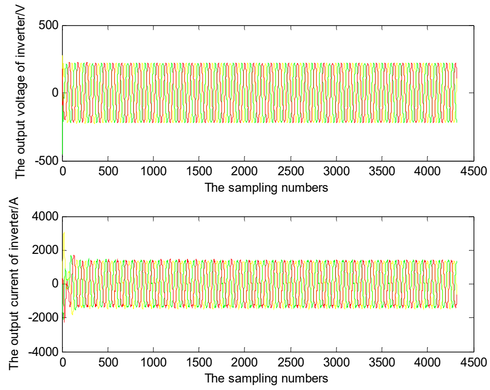


Figure. 6 Operating parameters of single PV grid-connected power system

The upper and lower two block diagrams in Figure. 6 represent the output voltage and the output current of the PV grid connected inverter, respectively. From Figure. 6, it can be seen that when the PV grid-connected power system is in the state of the normal grid operation or islanding operation, the operating parameters of the system have not changed basically, indicating that the island is in the most serious state at this time.

The power system simulation data of PSCAD is imported into Matlab for data processing. Then the characteristic frequency impedance signal of 250Hz is selected, the detection method proposed is tested, in which the sliding data window of 20ms is adopted.

5.1 The discrimination of harmonic impedance component islanding state under the condition of three-phase open circuit

Figure. 7 is the waveform of the 250Hz dq harmonic impedance component measured by the islanding detection method proposed under the condition of the three-phase open circuit.

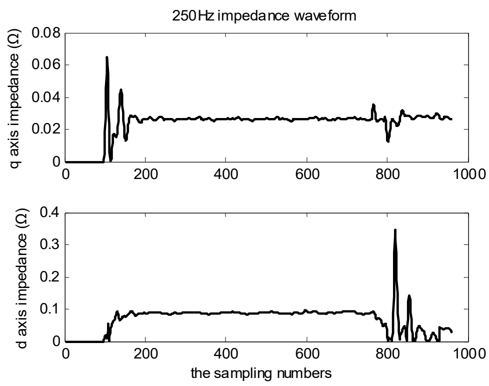


Figure. 7 250Hz dq harmonic impedance component waveform under the condition of the three-phase open circuit

In the grid connected operation, the 250Hz dq harmonic impedance component is equal to zero approximately. When the islanding fault occurs (the sampling number is 480), 250Hz dq harmonic impedance component does not change. After two cycles, the harmonic impedance components change gradually. Although the fault component of the 250Hz q axis impedance has changed, the fault component is less than the setting value. And the 250Hz d axis impedance fault component is greater than the setting value, which is in consistent with the set conditions. Considering the islanding detection logic, the islanding detection is successful.

5.2 The discrimination of harmonic impedance component islanding state under the condition of single-phase open circuit

Figure. 8 is the waveform of the 250Hz dq harmonic impedance component measured by the islanding detection method proposed under the condition of the single-phase open circuit.

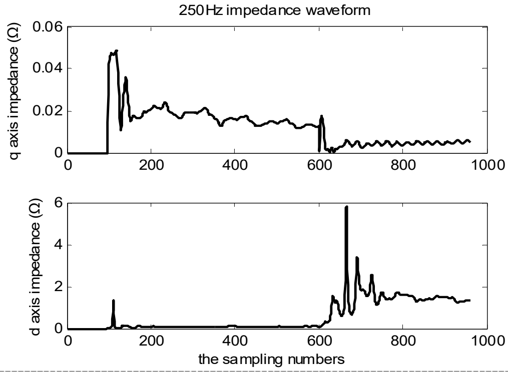


Figure. 8 250Hz dq harmonic impedance component waveform under the condition of the single-phase open circuit

In the grid connected operation, the 250Hz dq harmonic impedance component is equal to zero approximately, when the islanding fault occurs (the sampling number is 480), the dq component of each harmonic impedance does not change. After two cycles, the harmonic impedance components change gradually, although the fault component of the 250Hz q axis impedance has changed, the fault component is less than the setting value, the 250Hz d axis impedance fault component is greater than the setting value, which is in consistent with the set conditions. Considering the islanding detection logic, the islanding detection is successful.

5.3 The discrimination of harmonic impedance component islanding fault under the condition of two-phase open circuit

Figure. 9 is the waveform of the 250Hz impedance dq fault component measured by the islanding detection method proposed for the single-phase open circuit:

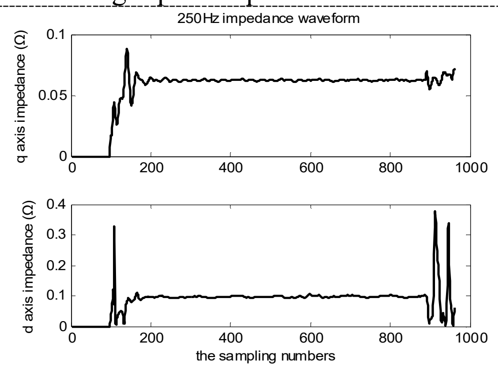


Figure. 9 250Hz dq harmonic impedance component waveform under the condition of two-phase open circuit

In the grid connected operation, the 250Hz dq harmonic impedance component is equal to zero approximately, when the islanding fault occurs (the sampling number is 480), the dq component of each harmonic impedance does not change. After two cycles, the harmonic impedance components change gradually, although the fault component of the 250Hz q axis impedance has changed, the fault component is less than the setting value, the 250Hz d axis impedance fault component is greater than the setting value, which is in consistent with the set conditions. Considering the islanding detection logic, the islanding detection is successful.

In summary, the dq impedance component method can detect the state of the island rapidly and effectively in the three-phase, single-phase and two-phase disconnection of the parallel switch, respectively. This method has the advantages of fast response speed, accurate test result, no detection blind area and no adverse effects on power quality.

6. Conclusion

In this paper, a new islanding detecting method is proposed which use dq harmonic impedance component to detect islanding state. The method implement the islanding detecting successfully using the difference of 250 Hz frequency impedance signals when the PV system is in parallel operation or island operation state. The method can detect island quickly and effectively, and it has no influence on the power quality and has no blind spot detection.

Acknowledgments

The Project Supported by Natural Science Basic Research Plan in Shaanxi Province of China (Program No.2017JM5138). The authors would like to express their heartful thanks to the research institute for its financial support for this work.

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